XIV. *New Experiments upon Heat.* *By Colonel Sir* Benjamin Thompſon, *Knt. F. R. S. In a Letter to Sir* Joſeph Banks, *Bart. P. R. S.*

Read March 9, 1786.

DEAR SIR,

I HAVE at length begun the courſe of experiments upon heat which I have ſo long had in contemplation ; and I have already made a diſcovery, which, if not new to you, is perfectly ſo to me, and which I think may lead to a further knowledge reſpecting the nature of heat.

VOL. LXXVI. O o Examining

Examining the conducting power of air, and of various other fluid and solid bodies, with regard to heat, I was led to examine the conducting power of the *Torricellian vacuum.* From the striking analogy between the electric fluid and heat respecting their conductors and non-conductors (having found that bodies, in general, which are conductors of the electric fluid, are likewise good conductors of heat, and, on the contrary, that electric bodies, or such as are bad conductors of the electric fluid, are likewise bad conductors of heat), I was led to imagine that the Torricellian vacuum, which is known to afford so ready a paffage to the electric fluid, would alfo have afforded a ready paffage to heat.

The common experiments of heating and cooling bodies under the receiver of an air-pump I concluded inadequate to determining this queftion; not only on account of the impoffibility of making a perfect void of air by means of the pump; but alfo on account of the moift vapour, which exhaling from the wet leather and the oil ufed in the machine, expands under the receiver, and fills it with a watery fluid, which, though extremely rare, is yet capable of conducting a great deal of heat: I had recourfe therefore to other contrivances.

I took a thermometer, unfilled, the diameter of whofe bulb (which was globular) was juft half an inch, Paris meafure, and fixed it in the center of a hollow glafs ball of the diameter of $1\frac{1}{4}$ Paris inch, in fuch a manner, that the fhort neck or opening of the ball being foldered faft to the tube of the thermometer $7\frac{1}{2}$ lines above its bulb, the bulb of the thermometer remained fixed in the center of the ball, and confequently was cut off from all communication with the external air. In the bottom of the glafs ball was fixed a fmall hollow tube or point, which projecting outwards was foldered

to

to the end of a common barometer tube about 32 inches in length, and by means of this opening the space between the internal surface of the glass ball and the bulb of the thermometer was filled with hot mercury, which had been previously freed of air and moisture by boiling. The ball, and also the barometrical tube attached to it, being filled with mercury, the tube was carefully inverted, and its open end placed in a bowl in which there was a quantity of mercury. The instrument now became a barometer, and the mercury descending from the ball (which was now uppermost) left the space surrounding the bulb of the thermometer free of air. The mercury having totally quitted the glass ball, and having sunk in the tube to the height of 28 inches (being the height of the mercury in the common barometer at that time), with a lamp and a blow-pipe I melted the tube together, or sealed it hermetically, about three-quarters of an inch below the ball, and cutting it at this place with a fine file, I separated the ball from the long barometrical tube. The thermometer being afterwards filled with mercury in the common way, I now possessed a thermometer whose bulb was confined in the center of a *Torricellian vacuum*, and which served at the same time as the body to be heated, and as the instrument for measuring the heat communicated.

Experiment N° 1.

With this instrument (see fig. 1. Tab. VI.) I made the following experiment. Having plunged it into a vessel filled with water, warm to the 18th degree of REAUMUR's scale, and suffered it to remain there till it had acquired the temperature of the water, that is

to

to fay, till the mercury in the inclofed thermometer ftood at 18°, I took it out of this veffel and plunged it fuddenly into a veffel of boiling water, and holding it in the water (which was kept conftantly boiling) by the end of the tube, in fuch a manner that the glafs ball, in the center of which was the bulb of the thermometer, was juft fubmerged, I obferved the number of degrees to which the mercury in the thermometer had arifen at different periods of time, counted from the moment of its immerfion. Thus, after it had remained in the boiling water 1 min. 30 fec. I found the mercury had rifen from 18° to 27°. After 4 minutes had elapfed, it had rifen to 44°$\frac{9}{10}$; and at the end of 5 minutes it had rifen to 48°$\frac{2}{10}$.

Experiment N° 2.

Taking it now out of the boiling water I fuffered it to cool gradually in the air, and after it had acquired the temperature of the atmofphere, which was that of 15° R. (the weather being perfectly fine), I broke off a little piece from the point of the fmall tube which remained at the bottom of the glafs ball, where it had been hermetically fealed, and of courfe the atmofpheric air rufhed immediately into the ball. The ball furrounding the bulb of the thermometer being now filled with air (inftead of being emptied of air, as it was in the before-mentioned experiment), I re-fealed the end of the fmall tube at the bottom of the glafs ball hermetically, and by that means cut off all communication between the air confined in the ball and the external air; and with the inftrument fo prepared I repeated the experiment before-mentioned; that is to fay, I put it into water warmed to 18°, and when it had acquired the tem-

perature

perature of the water, I plunged it into boiling water, and obferved the times of the afcent of the mercury in the thermometer. They were as follows:

	Time elapfed.	Heat acquired.
Heat at the moment of being plunged into the boiling water, . . .		18° R.
	M. S.	°
After having remained in the boiling water	0 45	27
	1 0	$34\frac{4}{10}$
	2 10	$44\frac{9}{10}$
	2 40	$48\frac{2}{10}$
	4 0	$56\frac{2}{10}$
	5 0	$60\frac{9}{10}$

From the refult of thefe experiments it appears evidently, that the Torricellian vacuum, which affords fo ready a paffage to the electric fluid, fo far from being a good conductor of heat, is a much worfe one than common air, which of itfelf is reckoned among the worft: for in the laft experiment, when the bulb of the thermometer was furrounded with air, and the inftrument was plunged into boiling water, the mercury rofe from 18° to 27° in 45 feconds; but in the former experiment, when it was furrounded by a Torricellian vacuum, it required to remain in the boiling water 1 minute 30 feconds = 90 feconds, to acquire that degree of heat. In the vacuum it required 5 minutes to rife to $48°\frac{2}{10}$; but in air it rofe to that height in 2 minutes 40 feconds; and the proportion of the times in the other obfervations is nearly the fame, as will appear by the following table.

The

| The bulb of the thermometer placed in the center of the glass ball, and | | | |
| surrounded by a Torricellian vacuum. (Exp. N° 1.) | | surrounded by air. (Exp. N° 2.) | |
Time elapsed.	Heat acquired.	Time elapsed.	Heat acquired.
Upon being plunged into boiling water	$18°$		$18°$
M. S.	°	M. S.	•
After remaining in it 1 30	27	0 45	27
		1 0	$30\frac{4}{10}$
4 0	$44\frac{9}{10}$	2 10	$44\frac{9}{10}$
5 0	$48\frac{2}{10}$	2 40	$48\frac{2}{10}$
		4 0	$56\frac{2}{10}$
		5 0	$60\frac{9}{10}$

These experiments were made at Manheim, upon the first day of July last, in the presence of Professor HEMMER, of the Electoral Academy of Sciences of Manheim, and CHARLES ARTARIA, Meteorological Instrument-maker to the Academy, by whom I was assisted.

Finding the construction of the instrument made use of in these experiments attended with much trouble and risque, on account of the difficulty of soldering the glass ball to the tube of the thermometer without at the same time either closing up, or otherwise injuring, the bore of the tube, I had recourse to another contrivance much more commodious, and much easier in the execution.

At the end of a glass tube or cylinder ten or eleven inches in length, and near three-quarters of an inch in diameter internally, I caused a hollow globe to be blown $1\frac{1}{2}$ inch in diameter,

meter,

meter, with an opening in the bottom of it correfponding
with the bore of the tube, and equal to it in diameter, leaving
to the opening a neck or fhort tube, about an inch or three-
quarters of an inch in length. Having a thermometer pre-
pared, whofe bulb was juft half an inch in diameter, and
whofe freezing point fell at about 2¾ inches above its bulb, I
graduated its tube according to REAUMUR's fcale, beginning at
0°, and marking that point, and alfo every tenth degree above
it to 80°, with threads of fine filk bound round it, which
being moiftened with lac varnifh adhered firmly to the tube.
This thermometer I introduced into the glafs cylinder and
globe juft defcribed, by the opening in the bottom of the
globe, having firft choaked the cylinder at about 2 inches from
its junction with the globe by heating it, and crowding its fides
inwards towards its axis, leaving only an opening fufficient to
admit the tube of the thermometer. The thermometer being
introduced into the cylinder in fuch a manner that the center
of its bulb coincided with the center of the globe, I marked a
place in the cylinder, about three-quarters of an inch above
the 80th degree or boiling point upon the tube of the inclofed
thermometer, and taking out the thermometer, I choaked the
cylinder again in this place. Introducing now the thermometer
for the laft time, I clofed the opening at the bottom of the
globe at the lamp, taking care, before I brought it to the fire,
to turn the cylinder upfide down, and to let the bulb of the
thermometer fall into the cylinder till it refted upon the lower
choak in the cylinder. By this means the bulb of the thermo-
meter was removed more than 3 inches from the flame of the
lamp. The opening at the bottom of the globe being now
clofed, and the bulb of the thermometer being fuffered to
return into the globe, the end of the cylinder was cut off to

4   within

within about half an inch of the upper choak. This being done, it is plain, that the tube of the thermometer projected beyond the end of the cylinder. Taking hold of the end of the tube, I placed the bulb of the thermometer as nearly as poffible in the center of the globe, and obferving and marking a point in the tube immediately above the upper choak of the cylinder, I turned the cylinder upfide down, and fuffering the bulb of the thermometer to enter the cylinder, and reft upon the firft or lower choak (by which means the end of the tube of the thermometer came further out of the cylinder), the end of the tube was cut off at the mark juft mentioned (having firft taken care to melt the internal cavity or bore of the tube together at that place), and a fmall folid ball of glafs, a little larger than the internal diameter or opening of the choak, was foldered to the end of the tube, forming a little button or knob, which refting upon the upper choak of the cylinder, ferved to fufpend the thermometer in fuch a manner that the center of its bulb coincided with the center of the globe in which it was fhut up. The end of the cylinder above the upper choak being now heated and drawn out to a point, or rather being formed into the figure of the fruftum of a hollow cone, the end of it was foldered to the end of a barometrical tube, by the help of which the cavity of the cylinder and globe containing the thermometer was completely voided of air with mercury; when, the end of the cylinder being hermetically fealed, the barometrical tube was detached from it with a file, and the thermometer was left completely fhut up in a Torricellian vacuum, the center of the bulb of the thermometer being confined in the center of the glafs globe, without touching it in any part, by means of the two choaks in the cylinder, and the button upon the end of the tube.

Of

Of thefe inftruments I provided myfelf with two, as nearly as poffible of the fame dimenfions; the one, which I fhall call N° 1. being voided of air, in the manner above defcribed; the other, N° 2. being filled with air, and hermetically fealed.

With thefe two inftruments (fee fig. 2.) I made the following experiments upon the 11th of July laft, at Manheim, between the hours of ten and twelve, the weather being very fine and clear, the mercury in the barometer ftanding at 27 inches 11 lines, REAUMUR's thermometer at 15°, and the quill hygrometer of the Academy of Manheim at 47°.

Experiments N° 3, 4, 5 and 6.

Putting both the inftruments into melting ice, I let them remain there till the mercury in the inclofed thermometers refted at the point 0°, that is to fay, till they had acquired exactly the temperature of freezing water or melting ice; and then taking them out of the ice I plunged them fuddenly into a large veffel of boiling water, and obferved the time required for the mercury to rife in the thermometers from ten degrees to ten degrees, from 0° to 80°, taking care to keep the water conftantly boiling during the whole of this time, and taking care alfo to keep the inftruments immerfed to the fame depth, that is to fay, juft fo deep that the point 0° of the inclofed thermometer was even with the furface of the water.

These experiments I repeated twice, with the utmoft care; and the following table gives the refult of them.

Thermometer N° 1.			Thermometer N° 2.		
Its bulb half an inch in diameter, fhut up in the center of a hollow glafs globe, $1\frac{1}{2}$ inch in diameter, *void of air*, and hermetically fealed.			Its bulb half an inch in diameter, fhut up in the center of a hollow glafs globe, $1\frac{1}{2}$ inch in diameter, *filled with air*, and hermetically fealed.		
Taken out of freezing water, and plunged into boiling water.			*Taken out of freezing water, and plunged into boiling water.*		
Time elapfed.		Heat acquired.	Time elapfed.		Heat acquired.
Exp. N° 3.	Exp. N° 4.		Exp. N° 5.	Exp. N° 6.	
		0°			0°
M. S.	M. S.	o	M. S.	M. S.	o
0 51	0 51	10	0 30	0 30	10
0 59	0 59	20	0 35	0 37	20
1 1	1 2	30	0 41	0 41	30
1 18	1 22	40	0 49	0 53	40
1 24	1 23	50	1 1	0 59	50
2 0	1 51	60	1 24	1 20	60
3 30	3 6	70	2 45	2 25	70
11 41	10 27	80	9 10	9 38	80

22 44   21 1 = total time of heating from 0° to 80°.
Total time from 0° to 70°:
M. S.
In Exp. N° 3. = 11 3
In Exp. N° 4. = 10 34

Medium = 10 48$\frac{1}{2}$

16 55   17 3 = total time of heating from 0° to 80°.
Total time from 0° to 70°:
M. S.
In Exp. N° 5. = 7 45
In Exp. N° 6. = 7 25

Medium = 7 35

It appears from thefe experiments, that the conducting power of air to that of the Torricellian vacuum, under the circumftances defcribed, is as $7\frac{35}{60}$ to $10\frac{48\frac{1}{2}}{60}$ inverfely, or as 1000 to 702 nearly; for the quantities of heat communicated being equal,

equal, the intenfity of the communication is as the times inverfely.

In thefe experiments the heat paffed through the furrounding medium *into* the bulb of the thermometer: in order to reverfe the experiment, and make the heat pafs *out of* the thermometer, I put the inftruments into boiling water, and let them remain therein till they had acquired the temperature of the water, that is to fay, till the mercury in the inclofed thermometers ftood at 80°; and then, taking them out of the boiling water, I plunged them fuddenly into a mixture of water and pounded ice, and moving them about continually in this mixture, I obferved the times employed in cooling as follows.

Thermometer N° 1.			Thermometer N° 2.		
Surrounded by a *Torricellian vacuum.*			Surrounded by *air.*		
Taken out of boiling water, and plunged into freezing water.			*Taken out of boiling water, and plunged into freezing water.*		
Time elapfed.		Heat loft.	Time elapfed.		Heat loft.
Exp. N° 7.	Exp. N° 8.		Exp. N° 9.	Exp. N° 10.	
		80°			80°
M. S.	M. S.		M. S.	M. S.	
1 2	0 54	70	0 33	0 33	70
0 58	1 2	60	0 39	0 34	60
1 17	1 18	50	0 44	0 44	50
1 46	1 37	40	0 55	0 55	40
2 5	2 16	30	1 17	1 18	30
3 14	3 10	20	1 57	1 57	20
5 42	5 59	10	3 44	3 40	10
Not obferved.	Not obferved.	0	40 10	Not obferved.	0

Total time of cooling from 80° to 10°.
                                        M. S.
              In Exp. N° 7.=16 4
              In Exp. N° 8.=16 16

                  Medium =16 10

Total time of cooling from 80° to 10°.
                                        M. S.
              In Exp. N° 9. =9 49
              In Exp. N° 10.=9 41

                  Medium=9 45

By

By thefe experiments it appears, that the conducting power of air is to that of the Torricellian vacuum as $9\frac{45}{60}$ to $16\frac{10}{60}$ inverfely, or as 1000 to 603.

To determine whether the fame law would hold good when the heated thermometers, inftead of being plunged into freez-ing water, were fuffered to cool in the open air, I made the following experiments. The thermometers N° 1. and N° 2. being again heated in boiling water, as in the laft experiments, I took them out of the water, and fufpended them in the middle of a large room, where the air (which appeared to be perfectly at reft, the windows and doors being all fhut) was warm to the 16th degree of REAUMUR's thermometer, and the times of cooling were obferved as follows.

(Exp. N° 11.) Thermometer N° 1. Surrounded by a Torricellian vacuum. Heated to 80°, and fufpended in the open air warm to 16°.		(Exp. N° 12.) Thermometer N° 2. Surrounded by air. Heated to 80°, and fufpended in the open air warm to 16°.	
Time elapfed.	Heat loft.	Time elapfed.	Heat loft.
	80°		80°
M. S.		M. S.	
Not obferved.	70°	Not obferved.	70°
1 24	60	0 51	60
1 44	50	1 5	50
2 28	40	1 34	40
4 16	30	2 41	30
10 12 = total time employed in cooling from 70° to 30°.		6 11 = total time employed in cooling from 70° to 30°.	

Here the difference in the conducting powers of air and of the Torricellian vacuum appears to be nearly the fame as in the foregoing experiments, being as $6\frac{11}{60}$ to $10\frac{12}{60}$ inverfely, or as 1000 to 605. I could not obferve the time of cooling from

80°

80° to 70°, being at that time bufied in fufpending the inftruments.

As it might poffibly be objected to the conclufions drawn from thefe experiments that, notwithftanding all the care that was taken in the conftructing of the two inftruments made ufe of that they fhould be perfectly alike, yet they might in reality be fo far different, either in fhape or fize, as to occafion a very fenfible error in the refult of the experiments ; to remove thefe doubts I made the following experiments.

In the morning towards eleven o'clock, the weather being remarkably fine, the mercury in the barometer ftanding at 27 inches 11 lines, REAUMUR's thermometer at 15°, and the hygrometer at 47°, I repeated the experiment N° 3. (of heating the thermometer N° 1. in boiling water, &c.) and immediately afterwards opening the cylinder containing the thermometer at its upper end, where it had been fealed, and letting the air into it, I re-fealed it hermetically, and repeated the experiment again with the fame inftrument, the thermometer being now furrounded with air, like the thermometer N° 2.

The refult of thefe experiments, which may be feen in the following table, fhews evidently, that the error arifing from the difference of the fhapes or dimenfions of the two inftruments in queftion was inconfiderable, if not totally imperceptible.

(Exp. N° 13.)	(Exp. N° 14.)
Thermometer N° 1	*The same Thermometer* (N° 1.)
Its bulb half an inch in diameter shut up in the center of a glass globe 1½ inch in diameter, *voided of air*, and hermetically sealed.	The glass globe, containing the bulb of the thermometer, being now *filled with air*, and hermetically sealed.
Taken out of freezing water, and plunged into boiling water.	*Taken out of freezing water, and plunged into boiling water.*

Time elapsed.	Heat acquired.	Time elapsed.	Heat acquired.
	0°		0°
M. S.	°	M. S.	°
0 55	10	0 32	10
0 55	20	0 32	20
1 7	30	0 43	30
1 15	40	0 50	40
1 29	50	1 1	50
2 2	60	1 24	60
3 21	70	2 38	70
13 44	80	10 25	80

24 48 = total time of heating from 0° to 80°.
Total time from 0° to 70° = 11′ 4″.

18 5 = total time of heating from 0° to 80°.
Total time from 0° to 70° = 7′ 40″.

It appears, therefore, from these experiments, that the conducting power of common atmospheric air is to that of the Torricellian vacuum as $7\frac{40}{60}$ to $11\frac{4}{60}$ inversely, or as 1000 to 602; which differs but very little from the result of all the foregoing experiments.

Notwithstanding that it appeared, from the result of these last experiments, that any difference there might possibly have been in the proportions or dimensions of the instruments N° 1. and N° 2. could hardly have produced any sensible error

in

in the refult of the experiments in queftion; I was willing,
however, to fee how far any confiderable alterations of fize in
the inftrument would affect the experiment: I therefore pro-
vided myfelf with another inftrument, which I fhall call *Ther-*
mometer N° 3. different from thofe already defcribed in fize,
and a little different in its conftruction.

The bulb of the thermometer was of the fame form and
fize as in the inftruments N° 1. and N° 2. that is to fay, it was
globular, and half an inch in diameter; but the glafs globe,
in the center of which it was confined, was much larger, being
3 inches $7\frac{1}{2}$ lines in diameter; and the bore of the tube of the
thermometer was much finer, and confequently its length, and
the divifions of its fcale, were greater. The divifions were
marked upon the tube with threads of filk of different colours
at every tenth degree, from 0° to 80°, as in the before-men-
tioned inftruments. The tube or cylinder belonging to the
glafs globe was 8 lines in diameter, a little longer than the
tube of the thermometer, and perfectly cylindrical from its
upper end to its junction with the globe, being without any
choak; the thermometer being confined in the center of the
globe by a different contrivance, which was as follows. To
the opening of the cylinder was fitted a ftopple of dry wood,
covered with a coat of hard varnifh, through the center or
axis of which paffed the end of the tube of the thermometer:
this confined the tube in the axis of the cylinder at its upper
end. To confine it at its lower end, there was fitted to it a
fmall fteel fpring, a little below the point 0°; which, being
confined round the tube of the thermometer, had three elaftic
points projecting outwards, which preffing againft the infide
of the cylinder, confined the thermometer in its place. The
total length of this inftrument, from the bottom of the globe
to

to the upper end of the cylinder, was 18 inches, and the freez-ing point upon the thermometer fell about 3 inches above the bulb; confequently it lay about $1\frac{1}{2}$ inch above the junction of the cylinder with the globe, when the thermometer was confined in its place, the center of its bulb coinciding with the center of the globe. Through the ftopple which clofed the end of the cylinder paffed two fmall glafs tubes, about a line in diameter, which being about a line longer than the ftopple were ftopped up occafionally with fmall ftopples fitted to their bores. Thefe tubes (which were fitted exactly in the holes bored in the great ftopple of the cylinder to receive them, and fixed in their places with cement) ferved to convey air, or any other fluid, into the glafs ball, without being under a neceffity of removing the ftopple clofing the end of the cylinder; which, in order to prevent the pofition of the thermometer from being eafily deranged, was cemented in its place.

I have been the more particular in the defcription of thefe inftruments, as I conceive it abfolutely neceffary to have a perfect idea of them in order to judge of the experiments made with them.

With the inftrument laft defcribed (which I have called *Thermometer* N° 3.) I made the following experiment. It was upon the 18th of July laft, in the afternoon, the weather va-riable, alternate clouds and fun-fhine; wind ftrong at S.E. with now and then a fprinkling of rain; barometer at 27 inches $10\frac{1}{2}$ lines, thermometer at $18°\frac{1}{4}$, and hygrometer va-riable from 44° to extreme moifture.

In order to compare the refult of the experiment made with this thermometer with thofe made with the thermometer N° 2. I have, in the following table, placed thefe experiments by the fide of each other.

(Exp.

(Exp. N° 15.) Thermometer N° 3. Its bulb half an inch in diameter, shut up in the center of a glass tube, 3 inches 7½ lines in diameter, and surrounded by air. *Taken out of freezing water, and plunged into boiling water.*		(Exp. N° 4. and N° 5.) Thermometer N° 2. Its bulb half an inch in diameter, shut up in the center of a glass globe, 1½ inch in diameter, and surrounded by *air*. *Taken out of freezing water, and plunged into boiling water.*			
Time elapsed.	Heat acquired.	Time elapsed.			Heat acquired.
	0°	Exp. N° 4.	Exp. N° 5.	Medium.	0₀
M. S.	°	M. S.	M. S.	M. S.	°
0 33	10	0 30	0 30	0 30	10
0 38	20	0 35	0 37	0 36	20
0 54	30	0 41	0 41	0 41	30
0 51	40	0 49	0 53	0 51	40
1 7	50	1 1	0 59	1 0	50
1 28	60	1 24	1 20	1 22	60
2 28	70	2 45	2 25	2 35	70
9 0	80	9 10	9 38	9 24	80
16 59 = total time of heating from 0° to 80°. Time from 0° to 70° = 7′ 59″.		16 55 17 3 16 59 = total time of heating from 0° to 80°. Time from 0° to 70° = 7′ 35″			

If the agreement of these experiments with the thermometers N° 2. and N° 3. surprised me, I was not less surprised with their disagreement in the experiment which follows.

Experiment N° 16.

Taking the thermometer N° 3. out of the boiling water, I immediately suspended it in the middle of a large room, where the air, which was quiet, had the temperature of 18°¼ R. and observed the times of cooling as follows:

Time elapsed.	Heat loft.
	80°
M.　S.	°
1　55	70
0　12	60
0　33	50
2　15	40
4　0	30

9　55 = total time of cooling from 80° to 30°.

Time from 70° to 30° = 8′ 0″; but in the experiment N° 2. with the thermometer N° 2. the time employed in cooling from 70° to 30° was only 6′ 11″. In this experiment, with the thermometer N° 3. the time employed in cooling from 60° to 30° was 7′ 48″; but in the above-mentioned experiment, with the thermometer N° 2. it was only 5′ 20″. It is true, the air of the room was fomewhat cooler when the former experiment was made than when this latter was made with the thermometer N° 3.; but this difference of temperature, which was only 2°¼ (in the former cafe the thermometer in the room ftanding at 16°, and in the latter at 18°¼) certainly could not have occafioned the whole of the apparent difference in the refults of the experiments.

Does air receive heat more readily than it parts with it? This is a queftion highly deferving of further inveftigation, and I fhall not fail to give it a full examination in the courfe of my projected inquiries; but leaving it for the prefent, I fhall proceed to give an account of the experiments which I have already made *.

It

* Conceiving it to be a ftep of confiderable importance towards coming at a further

It having been my intention from the beginning to examine the conducting powers of the artificial airs or gasses, the thermometer

further knowledge of the nature of heat, to afcertain, by indifputable evidence, its paffage through the Torricellian vacuum, and to determine, with as much precifion as poffible, the law of its motions in that medium; and being apprehenfive that doubts might arife with refpect to the experiments before defcribed, on account of the contact of the tubes of the inclofed thermometers in the inftruments made ufe of with the containing glafs globes, or rather with their cylinders; by which means it might be fufpected, that a certain quantity, if not all the heat acquired, might poffibly be communicated: to put this matter beyond all doubt, I made the following experiment.

In the middle of a glafs body, of a pear-like form, about 8 inches long, and 2½ inches in its greateft diameter, I fufpended a fmall mercurial thermometer, 5½ inches long, by a fine thread of filk, in fuch a manner that neither the bulb of the thermometer, nor its tube, touched the containing glafs body in any part. The tube of the thermometer was graduated, and marked with fine threads of filk of different colours bound round it, as in the thermometers belonging to the other inftruments already defcribed; and the thermometer was fufpended in its place by means of a fmall fteel fpring, to which the end of the thread of filk which held the thermometer being attached, it (the fpring) was forced into a fmall globular protuberance or cavity, blown in the upper extremity of the glafs body, about half an inch in diameter, where the fpring remaining, the thermometer neceffarily remained fufpended in the axis of the glafs body. There was an opening at the bottom of the glafs body, through which the thermometer was introduced; and a barometrical tube being foldered to this opening, the infide of the glafs body was voided of air by means of mercury; and this opening being afterwards fealed hermetically, and the barometrical tube being taken away, the thermometer was left fufpended in a Torricellian vacuum.

In this inftrument, as the inclofed thermometer did not touch the containing glafs body in any part, on the contrary, being diftant from its internal furface an inch or more in every part, it is clear, that whatever heat paffed *into* or *out of* the thermometer muft have paffed *through* the furrounding Torricellian vacuum: for it cannot be fuppofed, that the fine thread of filk, by which the thermometer was fufpended, was capable of conducting any heat at all, or at leaft any fenfible quantity. I therefore flattered myfelf with hopes of being able, with the

affiftance

thermometer N° 3. was conſtructed with a view to thoſe expe-
riments ; and having now provided myſelf with a ſtock of thoſe
different kinds of airs, I began with *fixed air*, with which, by

aſſiſtance of this inſtrument, to determine poſitively with regard to the paſſage of
heat in the Torricellian vacuum : and this, I think, I have done, notwithſtanding
that an unfortunate accident put it out of my power to purſue the experiments ſo
far as I intended.

This inſtrument being fitted to a ſmall ſtand or foot of wood, in ſuch a manner
that the glaſs body remained in a perpendicular ſituation, I placed it in my room,
by the ſide of another incloſed thermometer (N° 2.), which was ſurrounded by
air, and obſerved the effect of the variation of heat in the atmoſphere. I ſoon
diſcovered, by the motion of the mercury in the incloſed thermometer, that the
heat paſſed through the Torricellian vacuum ; but it appeared plainly from the
ſluggiſhneſs or great inſenſibility of the thermometer, that the heat paſſed with
much greater difficulty in this medium than in common air. I now plunged both
the thermometers into a bucket of cold water ; and I obſerved that the mercury
in the thermometer ſurrounded by air deſcended much faſter than that in the
thermometer ſurrounded by the Torricellian vacuum. I took them out of the
cold water, and plunged them into a veſſel of hot water (having no conveniencies
at hand to repeat the experiment in form with the freezing and with the boiling
water); and the thermometer ſurrounded by the Torricellian vacuum appeared
ſtill to be much more inſenſible or ſluggiſh than that ſurrounded by air.

Theſe trials were quite ſufficient to convince me of the paſſage of heat in the
Torricellian vacuum, and alſo of the greater difficulty of its paſſage in that
medium than in common air ; but, not ſatisfied to reſt my inquiries here, I took
the firſt opportunity that offered, and ſet myſelf to repeat the experiments which
I had before made with the inſtruments N° 1. and N° 2. I plunged this inſtru-
ment into freezing water, where I let it remain till the mercury in the incloſed
thermometer had deſcended to o° ; when, taking it out of the freezing water, I
plunged it ſuddenly into a veſſel of boiling water, and prepared myſelf to obſerve
the aſcent of the mercury in the incloſed thermometer as in the foregoing experi-
ments ; but unfortunately the moment the end of the glaſs body touched the
boiling water, it cracked with the heat at the point where it had been hermetically
ſealed, and the water ruſhing into the body, ſpoiled the experiment : and I have
not ſince had an opportunity of providing myſelf with another inſtrument to
repeat it.

means

means of water, I filled the globe and cylinder containing the thermometer; and ftopping up the two holes in the great ftopple clofing the end of the cylinder, I expofed the inftrument in freezing water till the mercury in the inclofed thermometer had defcended to 0°; when, taking it out of the freezing water, I plunged it into a large veffel of boiling water, and prepared myfelf to obferve the times of heating, as in the former cafes; but an accident happened, which fuddenly put a ftop to the experiment. Immediately upon plunging the inftrument into the boiling water, the mercury began to rife in the thermometer with fuch uncommon celerity, that it had paffed the firft divifion upon the tube (which marked the 10th degree, according to REAUMUR's fcale) before I was aware of its being yet in motion; and having thus miffed the opportunity of obferving the time elapfed when the mercury arrived at that point, I was preparing to obferve its paffage of the next, when all of a fudden the ftopple clofing the end of the cylinder was blown up the chimney with a great explofion, and the thermometer, which, being cemented to it by its tube, was taken along with it, and was broken to pieces, and deftroyed in its fall.

This unfortunate experiment, though it put a ftop for the time to the inquiries propofed, opened the way to other refearches not lefs interefting. Sufpecting that the explofion was occafioned by the rarefaction of the water which remained attached to the infide of the globe and cylinder after the operation of filling them with fixed air; and thinking it more than probable, that the uncommon celerity, with which the mercury rofe in the thermometer, was principally owing to the fame caufe; I was led to examine the conducting power of *moift air*, or air faturated with water.

For this experiment I provided myfelf with a new thermo-
meter N° 4. the bulb of which, being of the fame form as
thofe already defcribed *(viz.* globular) was alfo of the fame fize,
or half an inch in diameter. To receive this thermometer
a glafs cylinder was provided, 8 lines in diameter, and about
14 inches long, and terminated at one end by a globe 1½ inch
in diameter. In the center of this globe the bulb of the ther-
mometer was confined, by means of the ftopple which clofed the
end of the cylinder; which ftopple, being near 2 inches long, re-
ceived the end of the tube of the thermometer into a hole bored
through its center or axis, and confined the thermometer in its
place, without the affiftance of any other apparatus. Through
this ftopple two other fmall holes were bored, and lined with
thin glafs tubes, as in the thermometer N° 3. opening a paf-
fage into the cylinder, which holes were occafionally ftopped
up with fome ftopples of cork; but to prevent accidents, fuch
as I had before experienced from an explofion, great care was
taken not to prefs thefe ftopples into their places with any con-
fiderable force, that they might the more eafily be blown out
by any confiderable effort of the confined air.

Though in this inftrument the thermometer was not alto-
gether fo fteady in its place as in the thermometers N° 1. N° 2.
and N° 3. the elafticity of the tube, and the weight of the
mercury in the bulb of the thermometer, occafioning a fmall
vibration or trembling of the thermometer upon any fudden
motion or jar; yet I preferred this method to the others, on
account of the lower part of this thermometer being intirely
free, or fufpended in fuch a manner as not to touch, or have
any communication with, the lower part of the cylinder or
the globe: for though the quantity of heat received by the
tube of the thermometer at its contact with the cylinder at its
                                                              choaks,

choaks, in the inftruments N° 1. and N° 2. or with the branches of the fteel fpring in N° 3. and from thence communicated to the bulb, muft have been exceedingly fmall; yet I was defirous to prevent even that, and every other poffible error or inaccuracy, however fmall, that might arife.

Does humidity augment the conducting power of air?

To determine this queftion I made the following experiments, the weather being clear and fine, the mercury in the barometer ftanding at 27 inches 8 lines, the thermometer at 19°, and the hygrometer at 44°.

(Exp. N° 17.) *Thermometer* N° 4. Surrounded by air *dry* to the 44th degree of the quill hygrometer of the Manheim Academy. *Taken out of freezing water, and plunged into boiling water.*		(Exp. N° 18.) *The fame thermometer* (N° 4.) Surrounded by air rendered as *moift* as poffible by wetting the infide of the cylinder and globe with water. *Taken out of freezing water, and plunged into boiling water.*	
Time elapfed.	Heat acquired. 80°	Time elapfed.	Heat acquired. 0°
M. S.	°	M. S.	°
0 34	10	0 6	10
0 39	20	0 4	20
0 44	30	0 5	30
0 51	40	0 9	40
1 6	50	0 18	50
1 35	60	0 26	60
2 40	70	0 43	70
not obferved.	80	7 45	80
8 9 = total time of heating from 0° to 70°.		1 51 = total time of heating from 0° to 70°	

From thefe experiments it appears, that the conducting power of air is very much increafed by humidity. To fee if the fame refult would obtain when the experiment was reverfed, I now took the thermometer with the *moift air* out of the boiling water, and plunged it into freezing water; and moving it about continually from place to place in the freezing water, I obferved the times of cooling, as fet down in the following table. N. B. To compare the refult of this experiment with thofe made with *dry air*, I have placed on one fide in the following table the experiment in queftion, and on the other fide the experiment N° 19. made with the thermometer N° 2.

(Exp. N° 19.) *Thermometer* N° 4. Surrounded by *moift air.* *Taken out of boiling water, and plunged into freezing water.*		(Exp. N° 10.) *Thermometer* N° 2. Surrounded by *dry air.* *Taken out of boiling water, and plunged into freezing water.*	
Time elapfed.	Heat loft. 80°	Time elapfed.	Heat loft. 80°
M. S.	°	M. S.	°
0 4	70	0 33	70
0 14	60	0 34	60
0 31	50	0 44	50
0 52	40	0 55	40
1 22	30	1 18	30
2 3	20	1 57	20
4 2	10	3 40	10
9 8 = total time of cooling from 80° to 10°.		9 12 = total time of cooling from 80° to 10°.	

Though the difference of the whole times of cooling from 80° to 10° in thefe two experiments appears to have been very fmall,

fmall, yet the difference of the times taken up by the firft twenty or thirty degrees from the boiling point is very remarkable, and fhows with how much greater facility heat paffes in moift air than in dry air. Even the flownefs with which the mercury in the thermometer N° 4. defcended in this experiment from the 30th to the 20th, and from the 20th to the 10th degree, I attribute in fome meafure to the great conducting power of the moift air with which it was furrounded; for the cylinder containing the thermometer and the moift air, being not wholly fubmerged in the freezing water, that part of it which remained out of the water was neceffarily furrounded by the air of the atmofphere; which being much warmer than the water, communicated of its heat to the glafs; which, paffing from thence into the contained moift air as foon as that air became colder than the external air, was, through that medium, communicated to the bulb of the inclofed thermometer, which prevented its cooling fo faft as it would otherwife have done. But when the weather becomes cold, I propofe to repeat this experiment with variations, in fuch a manner as to put the matter beyond all doubt. In the mean time I cannot help obferving, with what infinite wifdom and goodnefs Divine Providence appears to have guarded us againft the evil effects of exceffive heat and cold in the atmofphere; for if it were poffible for the air to be equally damp during the fevere cold of the winter months as it fometimes is in fummer, its conducting power, and confequently its apparent coldnefs, when applied to our bodies, would be fo much increafed, by fuch an additional degree of moifture, that it would become quite intolerable; but, happily for us, its power to hold water in folution is diminifhed, and with it its power to rob us of our animal heat, in proportion as its

coldnefs is increafed. Every body knows how very difagreeable a very moderate degree of cold is when the air is very damp; and from hence it appears, why the thermometer is not always a juft meafure of the apparent or fenfible heat of the atmofphere. If colds or catarrhs are occafioned by our bodies being robbed of our animal heat, the reafon is plain why thofe diforders prevail moft during the cold autumnal rains, and upon the breaking up of the froft in the fpring. It is likewife plain from whence it is that fleeping in damp beds, and inhabiting damp houfes, is fo very dangerous; and why the evening air is fo pernicious in fummer and in autumn, and why it is not fo during the hard frofts of winter. It has puzzled many very able philofophers and phyficians to account for the manner in which the extraordinary degree or rather *quantity* of heat is generated which an animal body is fuppofed to lofe, when expofed to the cold of winter, above what it communicates to the furrounding atmofphere in warm fummer weather; but is it not more than probable, that the difference of the quantities of heat, actually loft or communicated, is infinitely lefs than what they have imagined? Thefe inquiries are certainly very interefting; and they are undoubtedly within the reach of well contrived and well conducted experiments. But taking my leave for the prefent of this curious fubject of inveftigation, I haften to the fequel of my experiments.

Finding fo great a difference in the conducting powers of common air and of the Torricellian vacuum, I was led to examine the conducting powers of common air of different degrees of denfity. For this experiment I prepared the thermometer N° 4. by ftopping up one of the fmall glafs tubes paffing through the ftopple, and opening a paffage into the cylinder, and by fitting a valve to the external overture of the

<div align="right">other.</div>

other. The inftrument, thus prepared, being put under the receiver of an air-pump, the air paffed freely out of the globe and cylinder upon working the machine, but the valve above defcribed prevented its return upon letting air into the receiver. The gage of the air-pump fhowed the degree of rarity of the air under the receiver, and confequently of that filling the globe and cylinder, and immediately furrounding the thermometer.

With this inftrument, the weather being clear and fine, the mercury in the barometer ftanding at 27 inches 9 lines, the thermometer at 15°, and the hygrometer at 47°, I made the following experiments.

(Exp. N° 20.) *Thermometer* N° 4. Surrounded by common air, barometer ftanding at 27 inches 9 lines. *Taken out of freezing water, and plunged into boiling water.*		(Exp. N° 21.) *Thermometer* N° 4. Surrounded by air rarefied by pumping till the barometer-gage ftood at 6 inches 11½ lines. *Taken out of freezing water, and plunged into boiling water.*		(Exp. N° 22.) *Thermometer* N° 4. Surrounded by air rarefied by pumping till the barometer-gage ftood at 1 inch 2 lines. *Taken out of freezing water, and plunged into boiling water.*	
Time elapfed.	Heat acquired. 0°	Time elapfed.	Heat acquired. 0°	Time elapfed.	Heat acquired. 0°
M. S.	°	M. S.	°	M. S.	°
0 31	10	0 31	10	0 29	10
0 40	20	0 38	20	0 36	20
0 41	30	0 44	30	0 49	30
0 47	40	0 51	40	1 1	40
1 4	50	1 7	50	1 1	50
1 25	60	1 19	60	1 24	60
2 28	70	2 27	70	2 31	70
10 17	80	10 21	80	not obferved.	80
7 36 = total time of heating from 0° to 70°.		7 37 = total time of heating from 0° to 70°.		7 51 = total time of heating from 0° to 70°.	

The

The refult of thefe experiments, I confefs, furprifed me not a little; but the difcovery of truth being the fole object of my inquiries (having no favourite theory to defend) it brings no difappointment along with it, under whatever unexpected fhape it may appear. I hope that further experiments may lead to the difcovery of the caufe why there is fo little difference in the conducting powers of air of fuch very different degrees of rarity, while there is fo great a difference in the conducting powers of air, and of the Torricellian vacuum. At prefent, I fhall not venture any conjectures upon the fubject; but in the mean time I dare to affert, that the experiments I have made may be depended on.

The time of my ftay at Manheim being expired (having had the honour to attend thither his moft Serene Highnefs the Elector Palatine Duke of Bavaria, my moft Gracious Mafter, in his late journey), I was prevented from purfuing thefe inquiries further at that time; but I fhall not fail to recommence them the firft leifure time I can find, which I fancy will be about the beginning of the month of November. In the mean time, to enable myfelf to purfue them with effect, I am fparing neither labour nor expence to provide a complete apparatus neceffary for my purpofe; and his Electoral Highnefs has been gracioufly pleafed to order M. ARTARIA (who is in his fervice) to come to Munich to affift me. With fuch a Patron as his moft Serene Highnefs, and with fuch an affiftant as ARTARIA, I fhall go on in my purfuits with chearfulnefs. Would to God that my labours might be as ufeful to others as they will be pleafant to me!

I fhall conclude this letter with a fhort account of fome experiments I have made to determine the conducting powers

of

of water and of mercury; and with a table, fhowing at one view the conducting powers of all the different mediums which I have examined.

Having filled the glafs globe inclofing the bulb of the thermometer N° 4. firft with water, and then with mercury, I made the following experiments, to afcertain the conducting powers of thofe two fluids.

(Exp. N° 23.) Thermometer N° 4. Surrounded by *water*. Taken out of freezing water, and plunged into boiling water.		(Exp. N° 24, 25, and 26.) Thermometer N° 4. Surrounded by *mercury*. Taken out of freezing water, and plunged into boiling water.			
		Time elapfed.			Heat acquired.
Time elapfed.	Heat acquired.	Exp.N°24.	Exp.N°25.	Exp.N°26.	
	0°				0°
M. S.	°	M. S.	M. S.	M. S.	
0 19	10	0 5	0 5	0 5	10
0 8	20	0 4	0 2	0 5	20
0 9	30	0 2	0 2	0 4	30
0 11	40	0 4	0 5	0 5	40
0 15	50	0 4	0 4	0 7	50
0 21	60	0 7	0 4	0 8	60
0 34	70	0 15	0 9	0 14	70
2 13	80	Not obferved.	0 58	Not obferved.	80
1 57 = total time of heating from 0° to 70°.		0 41	0 31	0 48 = total times of heating from 0° to 70°.	

The total times of heating from 0° to 70° in the three experiments with mercury being 41 feconds, 31 feconds, and 48 feconds, the mean of thefe times is $36\frac{2}{3}$ feconds; and as in the experiment with water the time employed in acquiring the fame degree of heat was 1′ 57″ = 117 feconds, it appears

from

from thefe experiments, that the conducting power of mercury to that of water, under the circumftances defcribed, is as 36⅔ to 117 inverfely, or as 1000 to 313. And hence it is plain, why mercury *appears* fo much hotter, and fo much colder, to the touch than water, when in fact it is of the fame temperature: for the force or violence of the fenfation of *hot* or *cold* depends not intirely upon the temperature of the body exciting in us thofe fenfations, or upon the degree of heat it actually poffeffes, but upon the *quantity* of heat it is capable of communicating to us, or receiving from us, in any given fhort period of time, or as the intenfity of the communication; and this depends in a great meafure upon the conducting powers of the bodies in queftion.

The fenfation of *hot* is the entrance of heat into our bodies; that of *cold* is its exit; and whatever contributes to facilitate or accelerate this communication adds to the violence of the fenfation. And this is another proof that the thermometer cannot be a juft meafure of the *fenfible* heat, or cold, exifting in bodies; or rather, that the touch does not afford us a juft indication of their *real* temperatures.
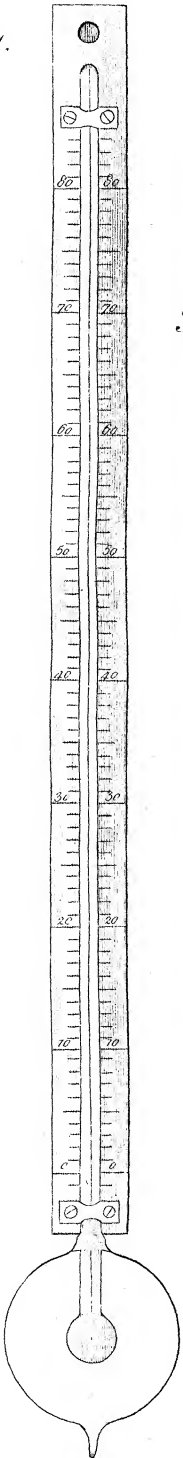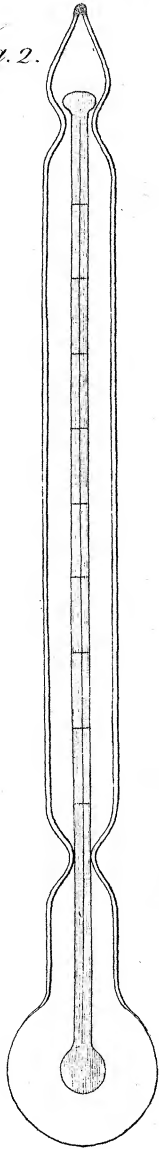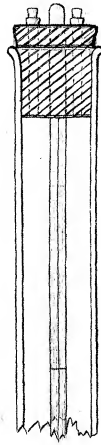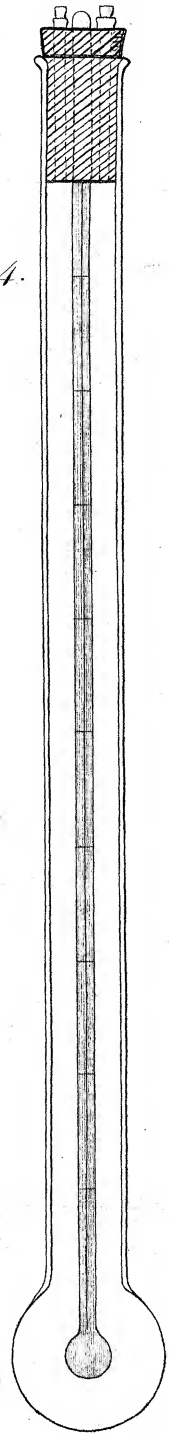
A Table

A Table of the *conducting Powers* of the under-mentioned *Mediums,* as determined by the foregoing experiments.

Thermom. N° 1. Torricellian Vacuum (Exp. N° 3. 4. and 13.)	Common air, denfity = 1, (Exp. N° 20.)	Rarefied air, denfity = $\frac{1}{4}$ (Exp. N° 21.)	Rarefied air, denfity = $\frac{1}{24}$ (Exp. N° 22.)	Moift air (Exp. N° 18.)	Water (Exp. N° 23.)	Mercury (Exp. N° 24, 25, and 26.)	Heat acquired.
		Thermometer N° 4. *Taken out of freezing water, and plunged into boiling water.* Time elapfed.					
M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.	0°
0 52	0 31	0 31	0 29	0 6	0 19	0 5	10
0 58	0 40	0 38	0 36	0 4	0 8	0 $3\frac{2}{3}$	20
1 3	0 41	0 44	0 49	0 5	0 9	0 $2\frac{2}{3}$	30
1 18	0 47	0 51	1 1	0 9	0 11	0 $4\frac{2}{3}$	40
1 25	1 4	1 7	1 1	0 18	0 15	0 5	50
1 58	1 25	1 19	1 24	0 26	0 21	0 $6\frac{1}{3}$	60
3 19	2 28	2 27	2 31	0 43	0 34	0 $12\frac{2}{3}$	70
11 57	10 17	10 21	——	7 45	2 13	0 58	80
10 53	7 36	7 37	7 51	1 51	1 57	0 $36\frac{2}{3}$ = total times of heating from 0° to 70°.	

In determining the relative conducting powers of thefe mediums, I have compared the times of the heating of the thermometers from 0° to 70° inftead of taking the whole times from 0° to 80°, on account of the fmall variation in the heat of the boiling water arifing from the variation of the weight of the atmofphere, and alfo on account of the very flow motion of the mercury between the 70th and the 80th degrees, and the difficulty of determining the precife moment when the mercury arrives at the 80th degree.

Taking

Taking now the conducting power of mercury = 1000, the conducting powers of the other mediums, as determined by thefe experiments, will be as follows, *viz.*

Mercury	1000
Moift air	330
Water,	313
Common air, denfity = 1	$80\frac{41}{1000}$
Rarefied air, denfity = $\frac{1}{4}$	$80\frac{23}{1000}$
Rarefied air, denfity = $\frac{1}{24}$	78
The Torricellian vacuum	55

And in thefe proportions are the quantities of heat which thefe different mediums are capable of tranfmitting in any given time; and confequently thefe numbers exprefs the rela- tive *fenfible* temperatures of the mediums, as well as their con- ducting powers. How far thefe decifions will hold good under a variation of circumftances experiment only can determine. This is certainly a fubject of inveftigation not lefs curious in itfelf than it is interefting to mankind; and I wifh that what I have done may induce others to turn their attention to this long neglected field of experimental inquiry. For my own part, I am determined not to quit it.

In the future profecution of thefe inquiries, I do not mean to confine myfelf folely to the determining of the conducting powers of fluids; on the contrary, folids, and particularly fuch bodies as are made ufe of for cloathing, will be principal fubjects of my future experiments. I have indeed already begun thefe refearches, and have made fome progrefs in them; but I forbear to anticipate a matter which I propofe for the fubject of a future communication.